Deformation Monitoring by means of Ground-based and Satellite SAR

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Extended abstract

The presentation will be focused on two main SAR (Synthetic Aperture Radar) techniques: terrestrial or Ground-based SAR (GBSAR) and satellite-based SAR. Both techniques make use of interferometry. Their main application is measuring and monitoring the deformation of land, structures and infrastructures.

Satellite-based SAR is a powerful tool to detect and monitor ground deformation. The presentation will introduce two main types of techniques: the classical technique, called Differential Interferometric SAR (DInSAR), and an advanced class of the DInSAR techniques, which is called Persistent Scatterer Interferometry (PSI). In the literature are described many examples of successful deformation monitoring results using different SAR sensors, which demonstrated the DInSAR and PSI potential for a wide range of applications. They include seismology, volcanology, glaciology, landslides, subsidence and uplift, urban monitoring, etc. The DInSAR and PSI techniques have experienced a major development in the last twenty-five years, which is mainly related to the progress accomplished through the exploitation of C-band data (ERS-1/2, Envisat and Radarsat missions). The data acquired by these satellites cover long periods of time, a key aspect to guarantee a long-term deformation monitoring. The advent, in 2007, of very high resolution X-band data (TerraSAR-X and CosmoSkyMed) enabled a major step forward in the PSI techniques (higher sampling density, higher sensitivity to displacements, etc.). A further significant improvement is expected to occur thanks to the data acquired by the sensor onboard the Sentinel-1 satellites. This includes an improved data acquisition capability (image coverage of 250 by 180 km) frequent revisiting time, free of charge to all users, etc.

The presentation will recall the basic principle of SAR interferometry (useful to generate digital elevation models) and Differential SAR interferometry (useful to monitor deformations). Examples of DInSAR results will be illustrated. It will then outline the basic principles of PSI. Some important remarks will be made, which concern the ambiguous nature of the main PSI observables (the differential interferometric phases), the line-of-sight mono-dimensional nature of the measurements derived by DInSAR and PSI, and the different sensitivity of the interferometric phase to terrain topography and terrain deformation.

The presentation will discuss in details the main PSI products. They include the deformation velocity maps and the deformation time series. Several examples will be considered to highlight the main characteristics and the pros and cons of such products. An interesting PSI byproduct is given by the so-called residual topographic error, which indicates the elevation of the measured point with respect to a digital terrain model or a digital surface model used in the PSI processing. Thanks to the residual topographic error, the PSI technique is able to provide advanced geocoding (3D positioning) of its products. This is key to interpret and exploit the deformation measurement products. Due to the high sensitivity to subtle deformations, the interferometric phases might contain a non-

negligible component related to thermal expansion, i.e. to the displacements that are caused by temperature differences in the imaged area between SAR acquisitions. This aspect will be discussed in detail.

The second part of the presentation will be focused on Ground-Based SAR (GBSAR) interferometry for deformation measurement. In the last decade, this technique has gained an increasing interest as a deformation measurement and monitoring tool. This is due to its specific characteristics, which make it complementary to many other existing deformation monitoring techniques. The GBSAR is a radar-based terrestrial remote sensing imaging system. It consists of a radar sensor that emits and receives a burst of microwaves, repeating this operation while the sensor is moving along a rail track. The imaging capability is achieved by exploiting the Synthetic Aperture Radar (SAR) technique. The length of the rail determines the cross-range resolution of the acquired images: the longer the rail, the higher the cross-range resolution. The GBSAR is based on a coherent radar system, which measures not only the amplitude but also the phase of the received radar signal. The phase measurements can be exploited, by using interferometric techniques, to derive information on the deformation and the topography of the measured scene. The main GBSAR application is deformation monitoring. Its high sensitivity to small deformations, the long range of its measurements (up to several kilometers) and its imaging capability, which allows the system to perform simultaneously a vast number of measurements, are interesting characteristics that make the GBSAR system complementary to other deformation measurement techniques.

The presentation will briefly introduce the GBSAR measurement principle. Two main GBSAR configurations will be described. In the most commonly used GBSAR configuration (continuous GBSAR), the radar is left installed in situ, acquiring data periodically, e.g. every few minutes. Deformations are estimated by processing sets of GBSAR images acquired during several weeks or months, without moving the system. By contrast, in the discontinuous GBSAR the radar is installed and dismounted at each measurement campaign, revisiting a given site periodically. This configuration is useful to monitor slow deformation phenomena. Examples of continuous and discontinuous GBSAR will be discussed.

The entire presentation is focused on interferometric data. However, it is worth mentioning that a non-interferometric GBSAR approach to derive deformation estimates can be used. This approach exploits the geometric content of GBSAR amplitude imagery and estimates deformation through image matching. It is less sensitive to deformation but it offers the advantages of yielding aliasing-free deformation estimates, which, in addition, are insensitive to atmospheric effects. An example on non-interferometric SAR will be illustrated.

The last part of the presentation will be focused on a particular configuration of the GBSAR: a Real Aperture Radar (RAR). The RAR provides a sampling along the range, i.e. along the target-to-sensor distance, but it is unable to resolve targets in the cross-range direction (by contrast, this can be done using a GBSAR). The key characteristic of the RAR is its capability to measure phases (and hence displacements) with a high temporal frequency. For this, it is able to monitoring the vibration characteristics of structures. It has a very high sensitivity to displacements, a capability to sample the vibrations in time at high frequencies (e.g. 100 Hz), and has non-contact and easy-to-make remote sensing capabilities. This sensor can be used in different fields, such as civil engineering, structural engineering, seismological engineering, etc. The presentation will illustrate the capability of a RAR system.